Aircraft Stability and Control
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Lecture- 02
Introduction to static stability

Yes dear friends, we were discussing about static stability, and we realized and we understood when it defines static stability, we are very clear that it is to do with initial tendency of that system, if it has initial tendency to come back to the equilibrium. Then, the body of the system is in static stability okay. And we try to understand this through a diagram here, this is the spring and this is the mass.

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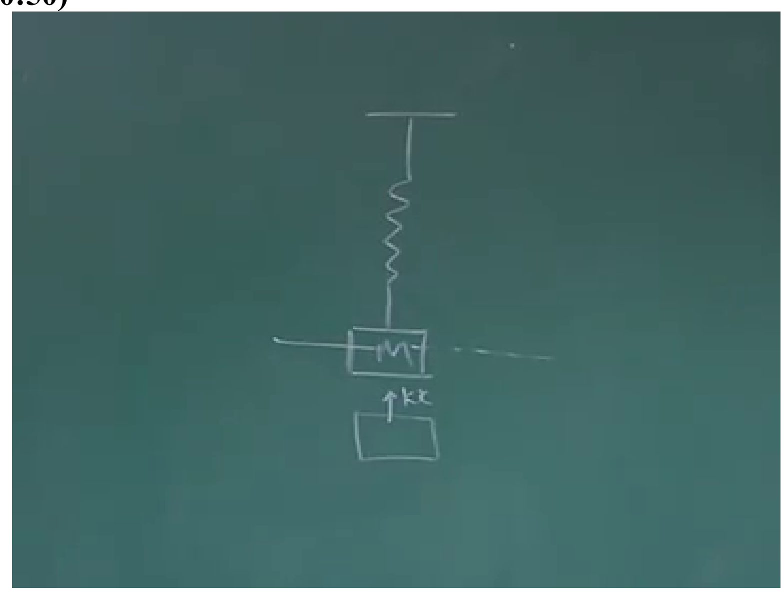

So, this is the equilibrium and equilibrium means all the net forces and movements are zero and once we want to understand static stability, what we say we disturb this, we stretch this mass, and release it and we know that the moment I stretch it there is a force KX, proportional to the displacement, it tries to take it back to the equilibrium it may over shoot it may oscillates the different issue, for static stability those things are not important for static stabilities only important that, it should have initial tendency to go towards the equilibrium that is static stability.

Now for this mass spring system, who is providing these static stability characteristics? It is through the spring the moment I stress the spring there is a opposing force, which tries to take it back to the equilibrium. Now let us come back to the aircraft, If I say for aircraft for time being If we concentrate on the angular stability that is suppose the airplane is going like this, and If there is a disturbance which tries to take the altitude up or he have to check.

It will be statically stable if it has initial tendency to come back to the same equilibrium. Okay, or to the equilibrium that initial tendency that means for a mass spring system, it has a spring who does all these works but for an aircraft what is that agency who will ensure that the moment I am deviating from the equilibrium, they will be a restoring moment which will try to take back it to the equilibrium.

That is, if it is going like this if it is disturbed and its altitude has increased then the aircraft would have a mechanism which should try to give a nose down movement, to ensure that it has static stability is it clear, now the question is for a mass spring system there are physical systems like spring, mass, a spring is giving that force or forces however for an aircraft all these forces are being generated to the interaction between body, and the medium which is air in this case right.

For example you know aircraft has major component as wings as horizontal tail vertical tail so, whatever disturbance it experiences if at all in a restoring movement has to be generated, it has to come from the interaction of the horizontal tail, wing, fuselage from their interaction it should generate a nose down movement, as long as it generate nose down movement for a positive disturbance, angular disturbance, angle of a attack disturbance, we will say it has static stability.

Now we will try to understand where from it will generate restoring movement almost analogous to spring.

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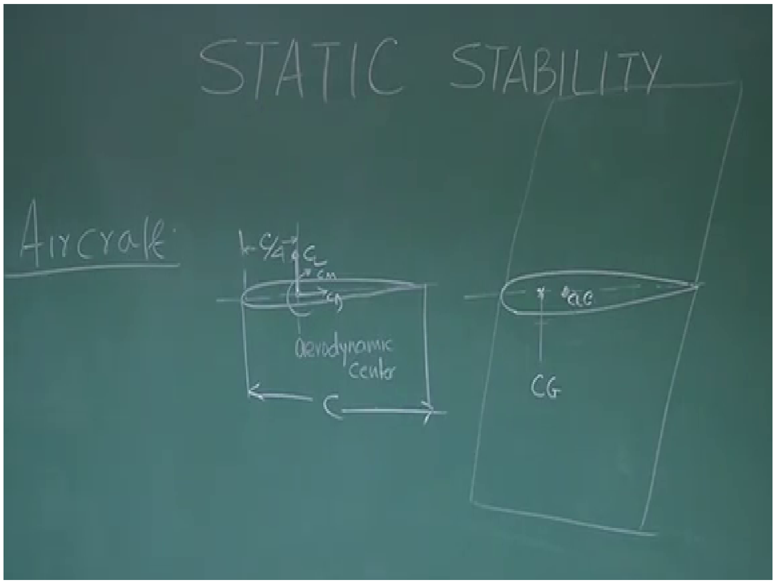

Okay let us see we all are aware of aerofoil, let's for simplicity assume that this is a symmetric aerofoil, and also we know there is a point called aerodynamic center, and what is the definition of aerodynamic center? It is a fictitious point mostly low speed. And moderately thickness to chord ratio aerofoil, this point is at C by 4, that is its location is C by 4 and we call it quarter chord point where we are now very clear what is a chord.

And what is the technical definition of this aerodynamic center? It is that point in that aerofile about which the pitching movement is independent of a angle of attack, is this clear? And even if I change angle of a attack, the pitching movement about that point will be zero right. So it is very convenient to represent all the forces and movement, acting at C by 4 so you will find that for a aerofoil I will represent like this CL, CD and in general there will be a CM okay.

Now let us try to understand how such configuration can generate a restoring movement, to ensure it has static stability that is the question we are addressing. It is important to understand that in free flight if there is any disturbance from the body, it will try to rotate about an axis passing through center of gravity so, we will like to see whatever movement is being generated, all the rotation about an axis passing through center of gravity.

So what do we do we say suppose this is the aerofoil, and I can now imagine that this aerofoil is a cross sectional contour of a wing, we are very clear we have already discussed the aerofoil is two dimensional concept, where the flow is supposed to follow the contour, there are no lateral flows but, for a wing there will be lateral flows but the wing contour is decided by the aerofoil, also we know lifting characteristics of the wing also depends upon what type of aerofoil we have chosen right.

But what we are trying to focus is on stability, mostly static stability at this point, so this is aerodynamic center, let us say this wing I want to fly okay, it has enough area now there are 2 positions at possible one is let's say center of gravity of the wing is ahead of aerodynamic center correct If this is the situation let's see what happens, let's say this gentleman is flying at Alpha = Alpha star and that is the equilibrium.

And because of some disturbance Delta Alpha the wing is going to respond we are looking for its initial tendency, If there is a Delta Alpha disturbance then the, and at Delta CL I say lift coefficient or a lift if I multiply it with dynamic pressure, will be generated and that can be represented effectively at aerodynamic center, we have agreed on this point. If this is true then what this Delta CL will do? This will generate a moment I say Delta CM about CG which will be nose down.

So if there is a positive disturbance of Delta Alpha this wing has a tendency to put the wing down to make this to zero or to come back to the Alpha star, so we say it has initial tendency and to come back to equilibrium, so we say if aerodynamic center is behind center of gravity then it processes static stability is it clear.

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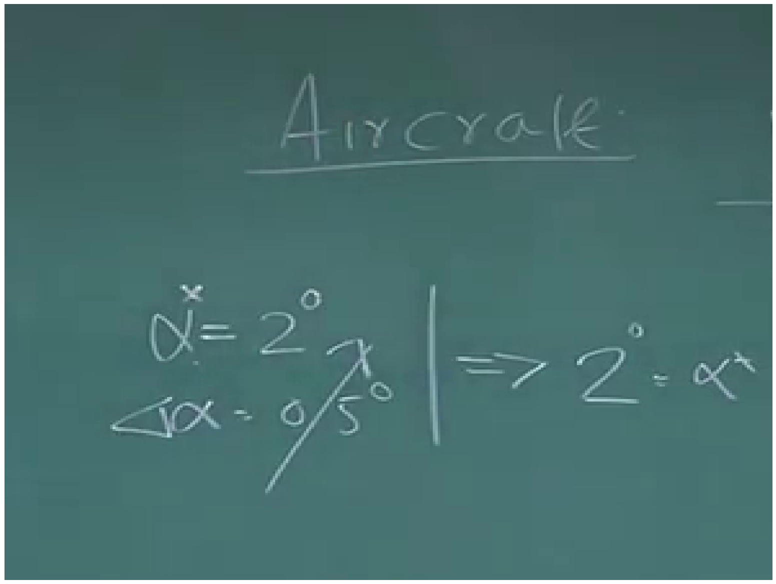

To be more elaborate suppose, the aircraft is trimmed at Alpha 2 degree, I call it Alpha star and there is a Delta Alpha. Let's say point 5 degree, If this is statically stable then what will happen, because of Delta Alpha now the angle of attack became, 2 + point 5, 2.5 degree, but if it is a statically stable the airplane will have a initial tendency or produce a nose down movement so, that finally this get cancelled or there is a tendency to cancel it, right. I will not use the word finally because finally once I say I am implicitly talking about time.

Which static stability had nothing to do with time that is dynamic stability, so correct statement will be the moment there is a changing angle of attack, from 2 + point 5 that is 2.5 degree, the airplane will generate a nose down movement to ensure that it has a initial tendency to come back to Alpha star 2 degree. And this is possible for a wing alone configuration only when, aerodynamic center is behind center of gravity, so you could see that the moment Delta CM.

Which is proportional to the angle is equivalent to the spring force KX, there also the spring force was proportional to a displacement that was a linear displacement there is a angular displacement clear, both are in opposing nature.

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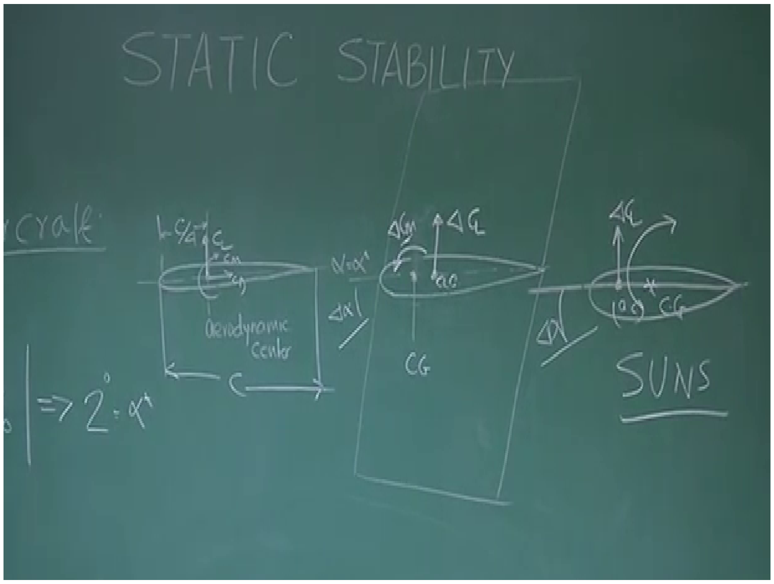

So that is how static stability is assured you can immediately see that, if this is the aerodynamic center and if CG is behind aerodynamic center or I say aerodynamic center is ahead of center of gravity.

Then what happens? if there is a disturbance Delta Alpha there will be a force here, let's say in non-dimensional form I call Delta CL, this will give nose up movement right so, this will actually take this way nose up so, further this angle will increase so such configuration doesn't have any initial tendency to come back to the equilibrium, so you say this is statically unstable. So what we are learning if we want to make a wing alone configuration statically stable.

I must ensure that aerodynamic center of the wing should be behind center of gravity of the wing right. And we also realized that, this production of moment, which is proportional to the angular displacement can be thought to be analogous to the production of force, because of linear displacement for a spring mass case so, I can always say these separation between aerodynamic center and center of gravity.

We have some relationship or some similarity with the stiffness of the system, like for mass spring system, the spring constant K it has some influence on the stiffness of the system, okay so this is this needs to be understood correctly before you again revisit my lecture on static stability okay.

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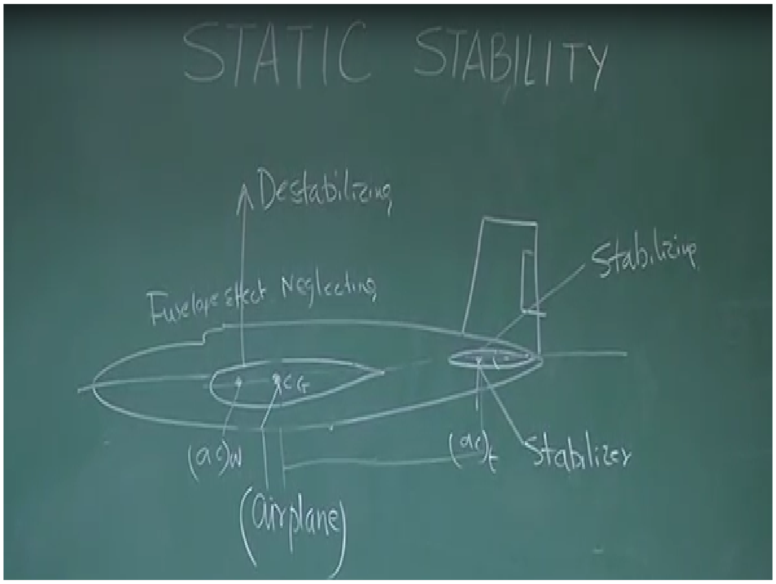

Now if you recall the aircraft has mainly this is the horizontal mainly those stabilizer component, and lifting component what is the lifting component? Primary lifting component is the wing that is wing has the primary role to generate lift, and these are this part is the stabilizer, and its role is this is typically horizontal stabilizer, its role is to give stability of the airplane correct. So now if I draw a configuration like this and let's say CG of the airplane is here, and aerodynamic center of the wing is here, and aerodynamic center of the tail is here.

So by seeing this diagram can we simply tell or can we not answer a question by seeing this description. And neglecting the fuselage effect so, let's say fuselage effect we are neglecting with this assumption, that we are neglecting fuselage effect by seeing the location of aerodynamic center, we service CG of the airplane this is CG of the airplane, please understand when I am drawing here this rotation this is CG of the airplane, earlier since it was only wing drive I was talking about CG of the wing, but this is a whole airplane this is the CG of the airplane why CG of the airplane.

Because aerplain will rotate in free space through an about an axis, which passes through CG of the air craft right, once I have represented the location of aero dynamic center of wing, as well as tail we saw with CG of the airplane I can easily comment, that this configuration will necessarily be statically stable. I am assuming there are no fuselage effects on neglecting fuselage effect why? I know because aerodynamic center of the wing is behind CG of the airplane.

So this will be stabilizing any way aerodynamic center of the tail is behind CG of the airplane, so this will be stabilizing so this aircraft has to be statically stable, there is no issue. Now think of it different case, think of a case where CG of the airplane is behind aerodynamic center of the wing, however aerodynamic center of the tail is behind CG of the airplane, can I directly say this aircraft will naturally be statically stable, I am assuming that in fuselage effect is neglected.

Can I directly tell let us investigate, as far as wing is concerned since aerodynamic center of the wing is ahead of CG it is giving destabilizing okay, so this is not giving stabilizing contribution because, I know for a stabilizing contribution aerodynamic center has to be behind center of gravity. But for tail it is of course behind for stabilizing, so whether the aircraft have adequate static stability or not or to be more stretch.

Whether the aircraft will be statically stable or not will be decided by the actual contribution of wing, which is destabilizing and the actual contribution of tail which is stabilizing and they will try to nullify each other, and how so ever wins that will decide statically stable or not. If the contribution of tail is more than the contribution of wing, than I will say statically stable.

For example, the restoring moment, which is primary reason for static stability in this case so, the restoring moment generated by the horizontal tail, if it is more than the disturbing moment or destabilizing moment generated by the wing, then only this airplane will be statically stable. The restoring moment is decided by what you could see not only the horizontal tail whatever lift is coming or area, but also the distance between the horizontal tail, aerodynamic center and the CG because, it is a moment okay.

So soon you will understand that, when we talk about static stability we talk about the area we talk about the momentum, and we define so term called tail volume ratio. So this is just to warming up, this concept should be clear to you also please understand.

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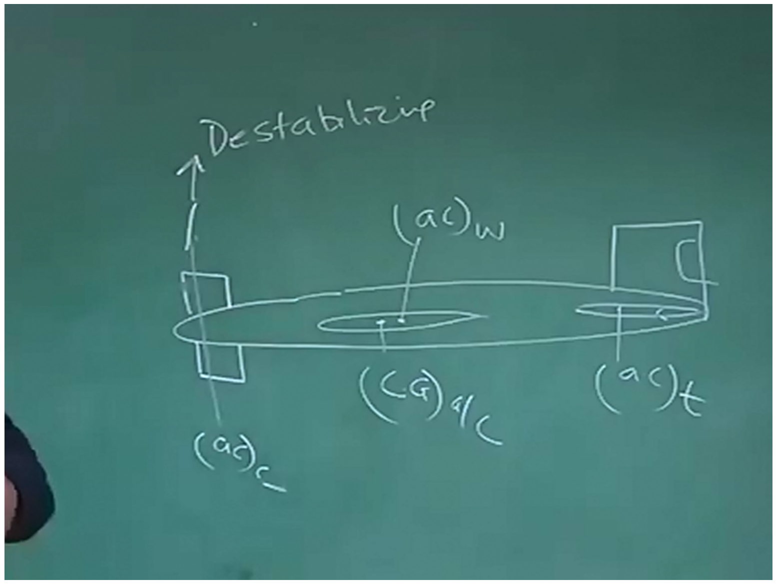

Suppose this is an airplane, let's say this is CG of the aircraft, and let us see AC of wing and of course this is AC of tail okay, let's say this is the configuration, again I am assuming fuselage contribution is neglected. If I see this I could easily check as, AC of the wing is behind CG of the aircraft, so this will give stabilizing contribution, a new AC of the ac of tail is behind the CG of the aircraft, this also give a stabilizing contribution.

So it is having naturally having static stability, but now suppose I add some surface here okay, which are typically called CANAD, then what will happen? The static stability will increase or decrease. How do I see this as a designer okay, I know that the moment it is like this the aerodynamic center of this CANAD, is ahead of CG of the aircraft, so what it will do it will give again destabilizing clear?

We know that aerodynamic center is ahead of center of gravity of the aircraft it will be destabilizing, clear. So whatever static stability it had without this CANAD, now the moment I put CANAD, its static stability will reduce, and if it is not properly designed, it may be become unstable also right statically unstable also.

So this is what the scenario and what is the gross learning for a designer, that any sub lifting surface please note this important any lifting surface, which are located behind the center of gravity of the airplane will generate stabilizing effect, any lifting surface which are located ahead of center of gravity will generate destabilizing contribution, If you understand this then major part of the static stability is understood.

It doesn't require more the knowledge level of class 11th or 12th you have to know how to find out the moments is it clear? okay let us take another example before, you go through the lectures.

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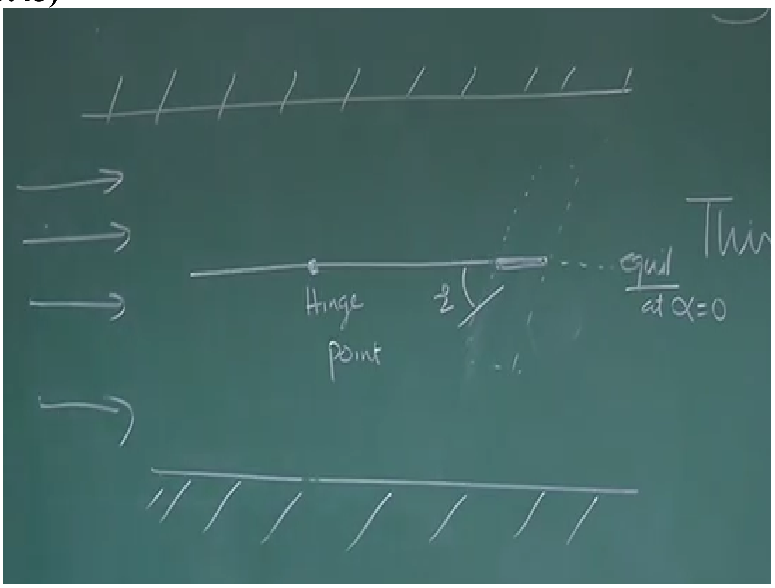

Let say very simple case, let us say this is the hinge point, and let us say I have put the horizontal surface like this, and I kept this in a wind tunnel, you were all aware of this normal nature you know what is a wind tunnel, okay when I say hinge point means so this is a horizontal tail.

So the lower end like this and it can rotate about this point in a pitch plain, and we say you remember we will call longitudinal motion right, but it cannot go forward or backward only 1 degree moves like this and now if this is the case, can we talk about whether this is statically stable or not?

What is the way to think you first identify what are the lifting surface, we have only one lifting surface, that is this one and you know the aerodynamic center will be C by four of this, so let's say this is the aerodynamic center, and now what is the check since it is rotating about hinge point, so it is like the center of gravity for a free space in free space also it rotates about center of gravity axis passing through center of gravity right?

So this is the hinge point so now this we could see aerodynamic center is behind the hinge point, so this will give necessarily static stability okay, as per our understanding but mechanics wise let us check how it happens, okay suppose these are systems and suppose I have given let me draw it clear once you understand this is the tail, so I am drawing the cross section okay assume the tail is something like this okay, so now I want to check whether it has static stability or not do we understand we have become expert.

We know the aerodynamic center is behind the CG of the hinge point in this case, so it will definitely contribute towards static stability right? Let us see by mechanics wise what happens let's introduce some disturbance of two degree remember this is the equilibrium okay? Equilibrium is at let say Alpha = 0 degree, now I introduce two degree disturbance, so equilibrium is at Alpha is = 0 I introduce a disturbance of two degree.

So what this two degree will do at C by 4 it will generate lift, I am representing by CL is coefficient, and we know very well if I multiply with the local dynamic pressure and area, I will get the total lift here is one assumption, generally as per definition the lift should be perpendicular to the velocity vector, but since Alpha is small to degree, we are assuming it to be straight that's all right, what this CL will do? This Cl this will immediately generate a moment about hinge point.

So which will also depend upon what is the length LT the moment you generate say nose down moment meaning thereby what? It will try to nullify this to degree so it has a initial tendency, to make or to it ensure it comes back to Alpha = 0 which is the equilibrium, so you say yes indeed it has static stability, is it clear?

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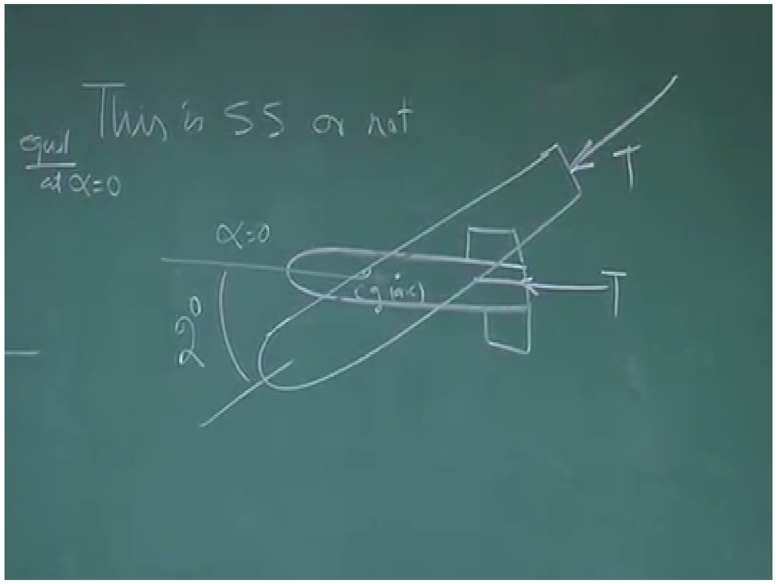

But there is a catch please understand what happens suppose I have fired a rocket, which has thrust T and it is statically stable. This is the CG and this is the aerodynamic center or center of pressure for this is statically stable, and it was having Alpha = 0 now, because of the disturbance of two degree what will happen? Because it is statically stable it has initial tendency to ensure that is two degree becomes 0 so that or the equilibrium Alpha = 0 is achieved so, it gives a nose down moment the moment it gives the nose down moment the rocket initially rocket turns like this but the thrust is on already,
right.

So it will have a serious effect on the range of the rocket because, it is supposed to go like this it is now turn like this, and thrust is on so the elevation angle will change so the range of the rocket will change, that is why it is important, when you talk about stability how much stability? So as far as static stability is concerned, it talks only about initial tendency, but it has larger influence on its sensitivity or in performance in dispersion the service wind.

So it is very, very important, we should also clearly know, how much static stability we want and our lecture will address this question, as I told you these are warm up for this course, my role is to orient you to a stability to understand and to have a love and hate relationship with static stability, you love it, don't love it too much, don't hate it okay. So how much I should love, and how much I should hate that will be decided by, what do you require and how much you understand. Okay clear.

So that’s why I always say static stability and control has a very tacky relationship, one has to respect it, if we don’t respect, the whole relationship can break and you may lead it to a disaster, okay. Thank you